U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

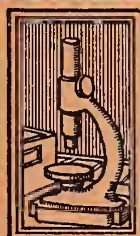
REPORT BMS25

Structural Properties of Conventional Wood-Frame Constructions for Walls Partitions, Floors, and Roofs

by

GEORGE E. HECK

NATIONAL BUREAU OF STANDARDS



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The Forest Products Laboratory of the United States Department of Agriculture is cooperating with both committees on investigations of wood constructions.

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ISSUED SEPTEMBER 13, 1939

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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Foreword

This report is one of a series issued by the National Bureau of Standards on the structural properties of constructions intended for low-cost houses and apartments. It deals with the determination of the properties of wood-frame construction. It differs from most of the other reports in the series in that no industrial or commercial concern sponsored the tests; instead the constructions were built and tested at the Forest Products Laboratory. The results afford a basis for comparing other and newer materials and types of construction.

This report embraces load-deformation relations and strength properties of wood-frame wall, partition, floor, and roof constructions. The constructions were subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods substantially as described in Report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions.

Lyman J. Briggs, *Director*.

Structural Properties of Conventional Wood-Frame Constructions, for Walls, Partitions, Floors, and Roofs

by GEORGE E. HECK*

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ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the Forest Products Laboratory built 39 specimens representing conventional wood-frame constructions for walls, partitions, floors, and roofs. In addition, six wall frames without covering were built.

The wall-frame specimens were subjected to compressive and transverse loads; the wall and partition specimens to compressive, transverse, concentrated, impact, and racking loads; the floor specimens to transverse, concentrated, and impact loads; and the roof specimens to transverse and concentrated loads. The transverse, concentrated, and impact loads were applied to both faces of wall specimens. For each of these loads three like specimens were tested. The deformation under load and the set after the load was removed were measured, except for concentrated loads, for which the set only was determined. The results are presented in graphs and in tables.

I. INTRODUCTION

Information on wood-frame construction and on masonry construction, both of which have been widely used and whose behavior in service is generally known, is desirable as a basis for judging the merits of the newer constructions included in the series of tests on the structural properties of low-cost house construction.

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Such information on masonry appears in report BMS5, Structural Properties of Six Masonry Wall Constructions. The present report deals with one type of wood-frame construction for each of the elements; walls, partitions, floors, and roofs, specimens of which were built and tested at the Forest Products Laboratory of the U. S. Department of Agriculture. The Laboratory and the University of Wisconsin, both in Madison, Wis., cooperate on problems related to wood and wood products.

In frame-house construction various species and grades of lumber are used for framing, wall and roof sheathing, and subflooring, with considerable diversity in the sizes, spacing, and arrangement of elements. Materials other than wood are used for wall sheathing and subflooring as well as for inside and outside finish faces, and a variety of materials serves as plaster base when plaster is used. Thus it is obviously impossible to select any one combination as the typical conventional wood-frame construction.

The principal features of the constructions, tests of which are reported herein, are:

Walls.—Studs (2 by 4 in. nominal) spaced 16 in. on centers and covered outside with bevel siding on diagonally placed sheathing boards and inside with gypsum plaster on wood laths.

Partitions.—Studs (2 by 4 in. nominal) spaced 16 in. on centers and covered on both sides with gypsum plaster on wood laths.

Floors.—Joists (2 by 8 in. nominal) spaced 16 in. on centers, cross-bridged at midspan, covered above with hardwood strip flooring over diagonally placed boards as subflooring, and below with gypsum plaster on wood laths.

Roof.—Rafters (2 by 6 in. nominal) spaced 24 in. on centers and covered above with wood shingles on sheathing boards laid perpendicular to the rafters.

All specimens tested were completed parts of walls, partitions, floors, and roofs except for the omission of paint, wallpaper, or other surfacing.

The estimated prices of these constructions in Washington, D. C., as of July 1937 are:

Wall	\$0. 43/ft²
Partition	. 31/ft²
Floor	. 49/ft²
Roof	. 27/ft²

In some other wood constructions tested by the National Bureau of Standards the framing was very similar, but the covering materials differed.

In addition to tests on specimens of the constructions outlined, tests were made on wall frames without any inner or outer covering.

The constructions were subjected to compressive, transverse, concentrated, impact, and racking loads, thus simulating loads to which the elements of a house are subjected in actual service.

The deflection under each increment of load and the set after its removal were determined, except for concentrated loads for which set only was measured. Maximum loads were also determined except in the impact-load test.

II. SPONSOR

No industrial or commercial concern participated in these tests as sponsor. The specimens were built by experienced workmen at the Forest Products Laboratory.

III. SPECIMENS AND TESTS

1. Specimens

Table 1 shows the construction symbols and specimen designations, the sizes of specimens, and manner of application of the loads.

Table 1.—*Test specimens*

Element	Construction symbol	Specimen designation	Kind of test	Size	Load applied
				ft	
Wall	*QA*	*C1, C2, C3*	Compressive	4× 8	Upper end.
Do	*QA*	*T1, T2, T3*	Transverse	4× 8	Inside face.
Do	*QA*	*T4, T5, T6*	do	4× 8	Outside face.
Do	*QA*	*P1, P2, P3* [a]	Concentrated		Inside face.
Do	*QA*	*P4, P5, P6* [a]	do	4× 8	Outside face.
Do	*QA*	*I1, I2, I3*	Impact	4× 8	Inside face.
Do	*QA*	*I4, I5, I6*	do	4× 8	Outside face.
Do	*QA*	*R1, R2, R3*	Racking	8× 8	End of top plate.
Wall frame [b]	*QAf*	*C1, C2, C3*	Compressive	4× 8	Upper end.
Do	*QAf*	*T1, T2, T3*	Transverse	4× 8	Either face.
Partition [c] (load-bearing)	*QD*	*C1, C2, C3*	Compressive	4× 8	Upper end.
Do	*QD*	*T1, T2, T3*	Transverse	4× 8	Either face.
Do	*QD*	*P1, P2, P3* [a]	Concentrated		Do.
Do	*QD*	*I1, I2, I3*	Impact	4× 8	Do.
Do	*QD*	*R1, R2, R3*	Racking	8× 8	End of top plate.
Floor	*QB*	*T1, T2, T3*	Transverse	4×12½	Upper face.
Do	*QB*	*P1, P2, P3* [a]	Concentrated		Do.
Do	*QB*	*I1, I2, I3*	Impact	4×12½	Do.
Roof	*QC*	*T1, T2, T3*	Transverse	4×14½	Do.
Do	*QC*	*P1, P2, P3* [a]	Concentrated	4×14½	Do.

[a] These specimens were undamaged portions of the specimens used for the transverse tests.
[b] The wall frames were tested to get a comparison between the bare frames and the specimens representing complete walls and partitions.
[c] Tests were not made on nonload-bearing partitions, because they are identical with load-bearing partitions.

Specific-gravity determinations (see tables 2 to 6) and photographic records of defects in the framing and sheathing indicate the quality of material in the different specimens. The character of the material in the various specimens is illustrated by several photographic figures in this report.

2. Plastering

The specimens were set up for plastering in the positions they would occupy in service. The plaster was applied by an experienced plasterer and struck to grounds projecting ¾ in. from the face of the frame. The laths were thoroughly sprinkled with water before the plaster was applied and the first coat was also sprinkled before application of the second coat. At least 1 day was allowed between the first and second plaster coats.

3. Test Procedure

The specimens were tested in accordance with BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, except for the compressive-load test in which a pin-end condition at the bottom rather than a flat-end condition was used. The walls and partitions are close to the dividing line between Euler columns and columns of intermediate length, and it was believed that in such instances a flat bearing at one end might result in an indeterminate increase in load above that corresponding to pin- or hinged-end conditions. In actual structures, vertical loads ordinarily cause compression at right angles to grain in horizontal parts at the top and bottom of the walls. Because the modulus of elasticity in compression at right angles to grain is low, there is no certainty of a significant fixity effect. A further consideration is that, because of the plasticity of wood under stress in compression perpendicular to grain and because of shrinkage and swelling with changes in moisture content, such fixity as may exist at time of erection may gradually decrease. It was therefore thought best to load the specimens through knife-edges at both ends in order to make certain that in test there would be no fixity.

Compressive-load tests were made later at the National Bureau of Standards to determine the difference in the results obtained on pin-end and flat-end bearings at the bottom. The results of these tests are given in section XIII.

The tests were begun February 15, 1938, and completed March 16, 1938. All plastered specimens were tested 28 days after the final coat of plaster was applied.

IV. MATERIALS

1. Wood

(a) *Framing*

All framing, i. e., studs, joists, plates, headers, and rafters, was No. 1 Douglas fir dimension. The average moisture content of this material was about 15 percent.

(b) *Sheathing*

Nominal 8-in. shiplap was used for the wall sections and 8-in. boards for the subfloor and roof. This sheathing lumber was No. 2 common southern yellow pine. When received it averaged about 25-percent moisture content. It was piled and stickered in a warm room and was at about 10-percent moisture content when the specimens were built.

(c) *Laths*

The laths were ⅜- by 1½-in. white pine wood laths 4 ft long.

(d) *Siding*

The siding was 6-in. bevel (actual width 5½ in.) western red cedar.

(e) *Shingles*

The shingles were 16-in. (five butts to 2 in.) edge-grain western red cedar.

2. Paper

The building paper applied over the wall sheathing, between the subfloor and the finish floor, and between the roof boards and the shingles was asphalt-impregnated and surface-treated sheathing paper weighing 50 pounds per roll of 500 ft ^{2}.

3. Plaster

(a) *Mix*

The plaster on wall, partition, and floor specimens consisted of two coats mixed accord-

ing to the manufacturer's recommendations in the proportions of 1 part of prepared gypsum plaster (U. S. Gypsum Co.) to 2 parts of plaster sand, by weight, for the first coat and 1 part of plaster to 3 parts of sand, by weight, for the second coat, with the necessary water to form a workable mixture.

(*b*) *Tensile Strength of Briquets*

Standard briquets were taken from each day's mixing of first and second coats to give an indication of plaster strength. These, as well as the specimens which they represented, were tested on the 28th day after completion of the plastering. The average tensile strength of the briquets was 175 and 115 lb/in.^{2} for the first and second coats, respectively.

4. Nails

The nails used in building the various specimens were the normal quality of wire nails usually obtained on the market. The size and number used in the different specimens are given under the description of each specimen.

V. WALL FRAMES *QAf*

1. Comments

The tests on wall frames without covering were included to obtain data that by comparison with data on wall and partition specimens would indicate the effect of sheathing, siding, and plaster on the structural properties of these constructions.

2. Description

The wall frames for compressive- and transverse-load tests were 4 ft wide by 8 ft high overall. They consisted of three studs spaced 16 in. on centers, with a stud at midwidth, a single floor plate, and a double top plate all of nominal 2- by 4-in. material, actual dimensions $1\frac{9}{16}$ by $3\frac{9}{16}$ in. The floor plate and the lower unit of the top plate were nailed with two 16d common wire nails driven through these parts into the ends of each stud. The upper unit of the top plate was fastened to the lower with three 10d common wire nails per stud space.

Three frames were tested under compressive and three under transverse load. Each frame for compressive load was braced to prevent bending of the studs in the plane of the frame. The braces consisted of five nominal 1- by 4-in. pieces, two at right angles to the studs at the one-third points of the frame height and three (one in each space) placed diagonally at about 45° to the studs (fig. 1).

3. Compressive Load

In compressive-load tests a small initial load was applied to hold the apparatus in place. Readings of shortening and deflection were taken under this initial load. Additional load was then applied until it reached a predetermined value and shortenings and lateral deflection were read after which the load was reduced to the initial value and readings of set made. This was repeated several times, increasing the load each time to a greater value than in the preceding application, and finally the load was increased continuously until failure occurred. The several values to which the load was increased before testing to failure are indicated by the graphs of test results. During the periods of load application, the movable head of the testing machine was operated at a speed of 0.064 in./min.

Wall frame *QAf–C3* after test is shown in figure 1.

The results for specimens *QAf–C1*, *C2*, and *C3* are given in table 2 and in figures 2 and 3.

Table 2.—*Structural properties of wall frame QAf*

[Average moisture content of the frames at time of test was 9.5 percent and the specific gravity (based on weight and volume oven dry) was 0.46]

Load	Load applied	Specimen designation	Maximum load	Remarks
			Kips/ft[a]	
Compressive	Eccentric to top plate.	*C1*	3.30	Failure by crushing at top plate by studs followed by rocking over of top plate.
		C2	4.28	Do.
		C3	3.46	Do.
	Average		3.68	
			lb/ft^2	
Transverse	One face	*T1*	213	Failure by tension through small knots in one stud.
		T2	159	Failure by tension in center stud.
		T3	175	Failure by tension in one outside stud.
	Average		182	

[a] A kip is 1,000 lb.

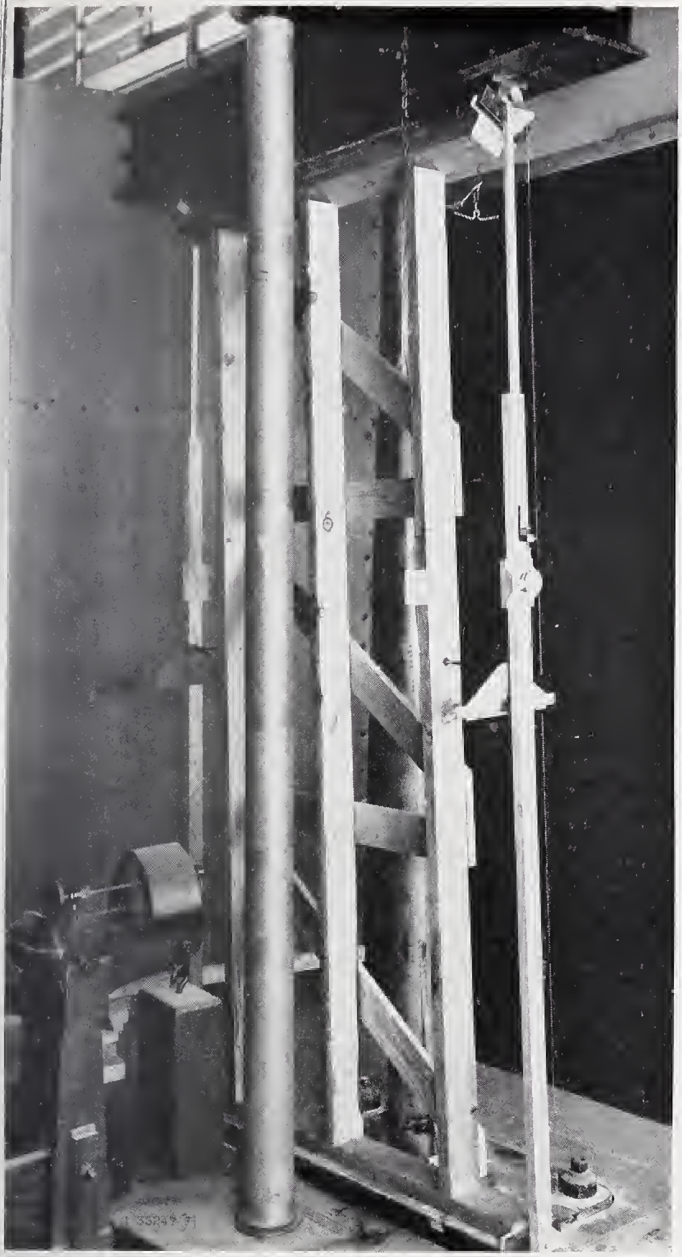

FIGURE 1.—*Failure of wall frame QAf–C3 under compressive load.*

Note rotation of top-plate assembly.

Failure occurred by crushing of the top plate at the studs accompanied by rocking over of this plate toward the eccentric-load side and pulling of the nails fastening the plate to the studs near the opposite edge.

Before testing these specimens in compression, the modulus of elasticity was determined for each one by making a load-deflection test within the proportional limit. The load was applied and the deflection measured as in the transverse-load test, except that no intermediate set readings were taken.

The average modulus of elasticity was 1,587,000 lb/in.^{2} (individual values were 1,670,000, 1,420,000, and 1,670,000 lb/in^2). Computations from this value show that had the wall frames acted as Euler columns, the average maximum load in the compressive-load test would have been approximately 34,200 lb, whereas the actual average was 14,710 lb.

4. Transverse Load

In the transverse test load was applied until it reached a predetermined value; the deflection was read; the load was removed; and the set was then read. This was repeated several times, increasing the load each time to a greater value than in the preceding application, and finally the load was increased continuously until failure occurred. The several values to which the load was increased before testing to failure are indicated by the graphs of test results.

During the periods of load application the movable head of the testing machine was operated at a rate of 0.135 in./min.

The results for specimens *QAf–T1*, *T2*, and *T3* are given in table 2 and in figure 4.

Failures were by tension in the studs.

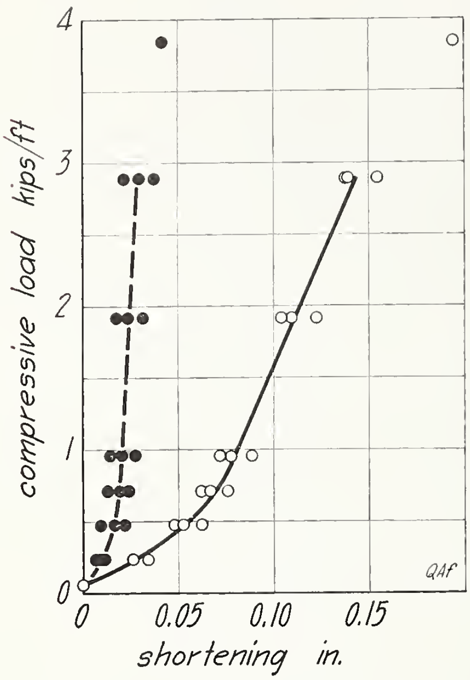

Figure 2.—*Compressive load on wall frames QAf.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *QAf-C1*, *C2*, and *C3*. Load applied to top end at one-third thickness of the frame from its face; to bottom end at center line of thickness. The loads are in kips per foot of width of specimen (length of floor and top plates 4 ft 0 in.).

VI. WALL *QA*

1. Description

Wall specimens for the compressive, transverse, and impact tests were 8 ft high by 4 ft wide, and those for the racking test were 8 ft high by 8 ft face width. The studs and plates were nominal 2 by 4's (actually 1$\frac{9}{16}$ by 3$\frac{9}{16}$ in.) spaced 16 in. on centers with a stud at midwidth of both the 4-ft and the 8-ft specimens. The floor plate and the lower unit of the double top plate were nailed with two 16d common wire nails driven through the plates into the ends of each stud. The upper unit of the double top plate was fastened to the lower with three 10d common wire nails per stud space.

Before lathing and plastering the specimens, the floor plate of each 8-ft specimen was securely nailed to a 6- by 6-in. timber about 10 ft long to facilitate handling and to prevent lateral deflection of the floor plate during test.

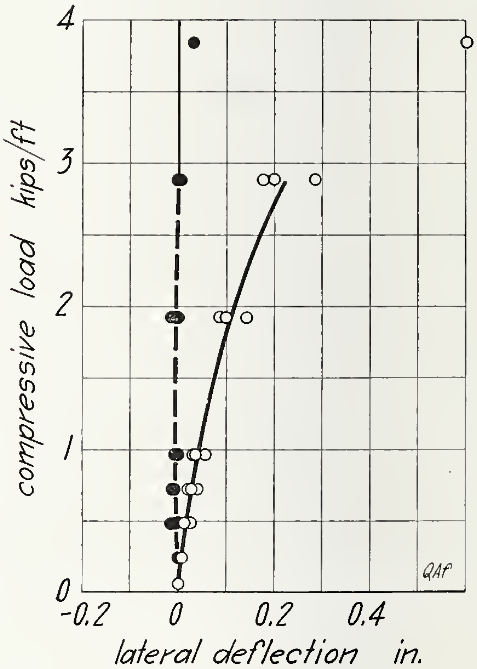

Figure 3.—*Compressive load on wall frames QAf.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) for specimens *C1*, *C2*, and *C3*. Load applied to top end at one-third thickness of the frame from its face; to bottom end at center of thickness. The loads are in kips per foot of width of specimen (length of floor and top plates 4 ft 0 in.).

Table 3.—*Structural properties of wall QA*

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the framing at time of test was 11.1 percent and the specific gravity (based on weight and volume when oven dry) was 0.50]

Load	Load applied	Specimen designation	Maximum height of drop [a]	Indentation at 100 lb	Maximum load	Remarks
			ft	*in.*	*Kips/ft* [b]	
Compressive	Eccentric to top plate.[c]	*C1*			8.55	Slight crushing of plaster at 2.75 kips/ft. First tension plaster crack at 8.15 kips/ft. Final failure due to crushing of plates at stud ends followed by bending failure in two studs. Bending of panel was toward the inside face.
		C2			7.79	Plaster crushed at 2.85 kips/ft. First tension crack in plaster at 7.63 kips/ft. Final failure by crushing at upper plate followed by cross-breaking of studs at 5.67 kips/ft after maximum load. Panel deflected toward inside face.
		C3			8.80	First failure in plaster was crushing near top at 4.75 kips/ft. Final failure due to crushing of upper plate followed by cross-breaking of two studs. Reverse bend—bending toward outside face at top but toward inside face at center and bottom.
	Average				8.38	
					lb/ft [2]	
Transverse	Inside (plastered) face.	*T1*			262	Tension in studs. First plaster crack at load points near maximum load.
		T2			267	Tension in studs. Plaster cracks under load points near maximum load.
		T3			289	Tension in one stud. Plaster cracks at load points visible only on removal of load after maximum load.
	Average				273	
Do	Outside (sheathed and sided) face.	*T4*			219	First plaster crack at 63 lb/ft [2] at seventh loading. Principal failure by tension in studs.
		T5			215	First plaster crack under load point at 42 lb/ft [2] at fifth loading. Tension at knot in outside stud followed by horizontal shear in center stud.
		T6			243	First plaster crack across center at 26 lb/ft [2] at fifth loading. Tension at knots in studs.
	Average				226	
					lb	
Concentrated	Inside (plastered) face.	*P1*		0.000	318	
		P2		.000	245	
		P3		.000	355	
	Average			0.000	306	
Do	Outside (sheathed and sided) face.	*P4*		0.001	1,520	Loaded at about 1 in. from sheathing joint.
		P5		.001	1,300	Loaded at about 1¾ in. from sheathing joint.
		P6		.000	2,050	
	Average			0.001	1,623	
Impact	Inside (plastered) face.	*I1*	9.0			First plaster crack at 2½-ft drop. Lath and plaster broke through near center at 9-ft drop. Outside face undamaged.
		I2	[a] 10.0			First plaster crack at 5-ft drop. Plaster badly shattered at 10-ft drop, but no failure in lath and studs. Outside face undamaged.
		I3	[a] 10.0			Do.
	Average					
Do	Outside (sheathed and sided) face.	*I4*	[a] 10.0			First plaster crack at 1½-ft drop. Most of plaster loose at 10-ft drop. Upper face and studs undamaged.
		I5	[a] 10.0			First plaster crack at 2½-ft drop. Plaster and some lath loose and failure of one outside stud at small knot at 10-ft drop.
		I6	[a] 10.0			First plaster crack at 2½-ft drop. Plaster and some lath loose and slight tension in one stud at small knot at 10-ft drop.
	Average		[a] 10.0			
					Kips/ft [b]	
Racking	End of top plate	*R1*			2.03	First plaster crack at 1.50 kips/ft. Final failure due to plaster shearing keys and sheathing shearing from floor plate with cross-breaking and splitting of studs.
		R2			2.15	First plaster crack at 0.88 kip/ft at last loading. Final failure similar to *R1*.
		R3			2.10	First plaster crack at 0.50 kip/ft at last loading. Final failure similar to *R1*.
	Average				2.09	

[a] Test discontinued at 10-ft drop.
[b] A kip is 1,000 lb.
[c] Specimens loaded on top plate through knife-edge at one-third width of frame from inside face of frame and supported at bottom on similar knife-edge at center of frame.

The sheathing on all walls was applied diagonally at an angle of about 45° with the studs and nailed with two 8d common wire nails at crossing of studs, floor plate, and upper unit of the double top plate and with one 8d nail at each crossing of the lower unit of the top plate, then covered with sheathing paper and finally bevel siding. The 4-ft specimens had no joints in the sheathing boards. The 8-ft specimens had joints in sheathing boards located at stud crossings, as indicated in figure 5.

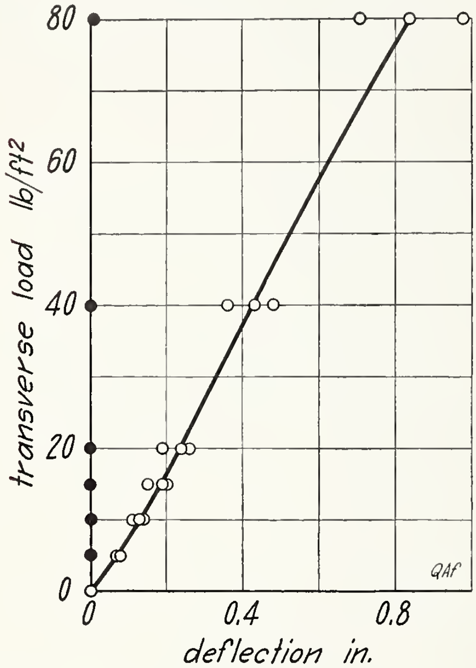

FIGURE 4.—*Transverse load on wall frames QAf.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *T1*, *T2*, and *T3* on the span of 7 ft 6 in. The loads are in pounds per square foot on the area of 30 sq ft (span times the length of wall represented by the 4-ft specimen).

Twenty-one widths of bevel siding were applied to each specimen with a resulting average exposure of 4 9/16 in., the top piece being ripped to this dimension. The actual widths of the siding being 5½ in., the average "overlap" was 15/16 in., and one 7d siding nail was driven through the overlapping edges at each stud crossing.

The inner faces of outside walls were lathed and given two coats of gypsum plaster to a combined thickness of lath and plaster of ¾ in. The laths were nailed with one 3d sterilized, blued lath nail at each stud crossing. The laths were applied in courses of eight laths each, the joints being broken in a uniform manner for each size of specimen, 51 widths of lath being required in each instance. Support for the 8-in. overhang of the lath at each edge of the 4-ft specimens was provided in conjunction with the plastering grounds, the supporting pieces being removed before test (fig. 6).

2. Compressive Load

The operation of the testing machine was as described for wall frames under section V–3.

The results for wall specimens *QA–C1*, *C2*, and *C3* are shown in table 3 and in figures 7 and 8.

The average maximum load of 8.38 kips/ft is approximately 60 percent of the value computed by inserting in the Euler column formula the average value of stiffness (*EI*) derived from the transverse-load tests on specimens *QA–T1*, *T2*, and *T3*.

The failures were characterized by crushing of the plaster near the plates, crushing of the plates at the ends of the studs, tension plaster cracks after maximum load, and finally cross-breaking of the studs. In specimens *C1* and *C2* bending was toward the inside face (negative deflection) despite the fact that the load was eccentric toward that face. The resultant greater crushing of the upper plates at the edge toward the sheathed outer face is illustrated by figure 9. Specimen *C3* took a reverse bend, the deflection being toward the outside face in the upper half, but toward the inside face at and below the center of the height.

3. Transverse Load

The operation of the testing machine was as described for wall frames under section V–4.

A specimen (*QA–T1*) under transverse-load test is shown in figure 10. The results of the tests are shown in table 3 and in figures 11 and 12, respectively, for specimens *QA–T1*, *T2*, and *T3* loaded on the inside face, and for specimens *QA–T4*, *T5*, and *T6* loaded on the outside face.

With the load applied to the outside face, the first failure was by cracking of the plaster. When the load was applied to the inside (plas-

Figure 5.—*Wall specimen QA before application of laths, plaster, or siding, showing construction of 8- by 8- ft. specimens and position of joints in sheathing (indicated by x's).*

In racking tests the horizontal forces were applied in the direction to cause tension in the sheathing, i. e., pushing toward the right at the top of the specimen and toward the left at the bottom.

tered) face, cracks were not observed until near the maximum load and were usually not visible until the load was removed.

4. Concentrated Load

A specimen (*QA–P3*) set up for the concentrated-load test is shown in figure 13. The micrometer dial and supporting bar shown in this figure are removed when making the indentation. The circular supporting ring remains in place.

The results are given in table 3 for wall specimens *QA–P1*, *P2*, and *P3* loaded on the inside face, and in table 3 and figure 14 for wall specimens *QA–P4*, *P5*, and *P6* loaded on the outside face. Indentation on the plastered face was negligible up to the point where the plaster crushed or cracked, consequently only the indentation at 100 lb was recorded for specimens *QA–P1*, *P2*, and *P3*.

When loaded on the inside (plastered) face, failure occurred by crushing and cracking of the plaster and breaking of the laths. When loaded on the outside face, failure occurred by crushing of the siding under the tool, and splitting and cross-breaking of the sheathing.

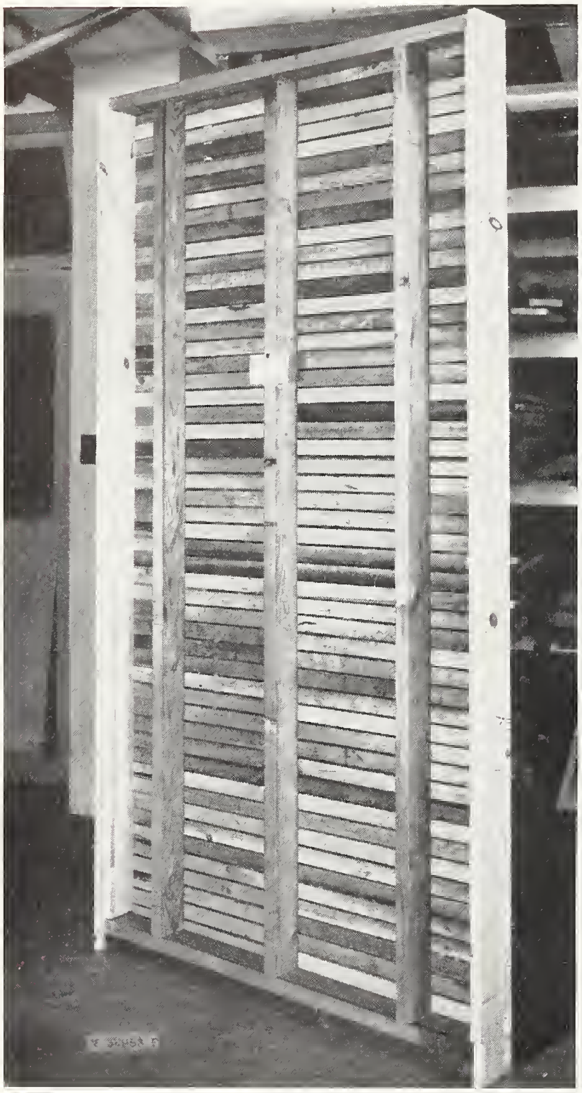

FIGURE 6.—*Partition specimen QD–T1 with laths on one face only.*

The pieces shown at vertical edges formed supports for lath ends and grounds for plastering and were removed before the specimen was tested.

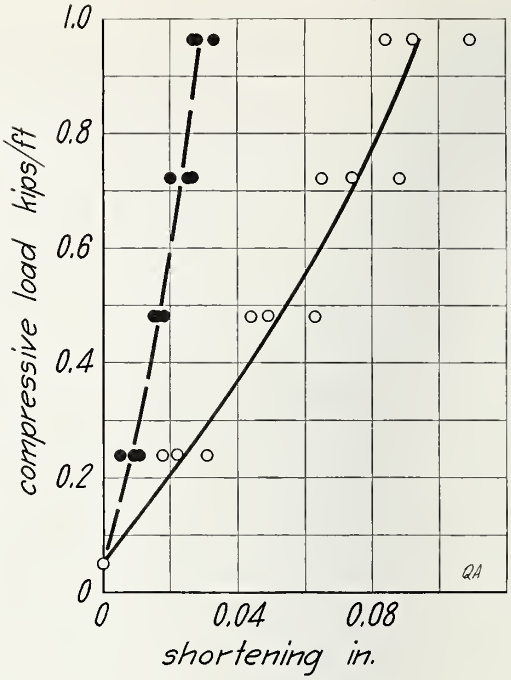

FIGURE 7.—*Compressive load on wall QA.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *QA–C1*, *C2*, and *C3*. The loads are in kips per foot of width of specimen (4 ft 0 in).

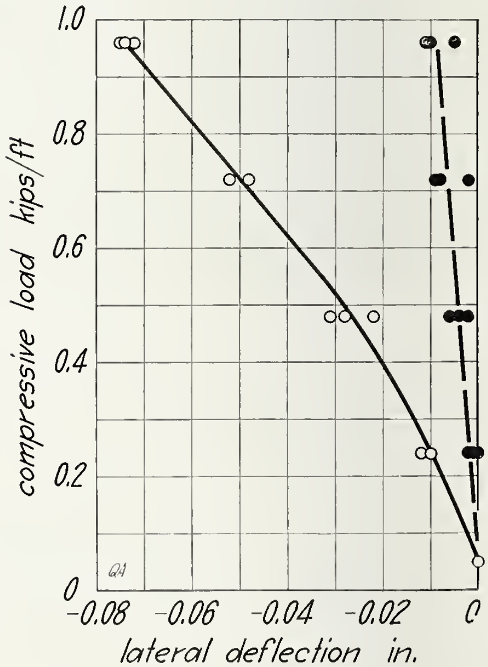

FIGURE 8.—*Compressive load on wall QA.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *QA–C1*, *C2*, and *C3*. The loads are in kips per foot of width of specimen (4 ft 0 in).

Figure 9.—*Crushing of lower face of upper plate against ends of studs in compressive-load test of specimen QA–C2.*

5. Impact Load

The results of the impact-load tests are given in table 3 and in figures 15 and 16, respectively, for specimens *QA–I1*, *I2*, and *I3* loaded on the inside face, and for specimens *QA–I4*, *I5*, and *I6* loaded on the outside face.

No failure occurred in the frame members of the wall panels up to the final drop from a height of 10 ft. In tests with the outside face up, most of the plaster and some of the laths had broken loose at this drop. Specimens tested with the inside (plastered) face up sustained only a general loosening of the plaster, and in one specimen (*I1*) the laths broke through near the center at the 9-ft drop.

6. Racking Load

In the racking-load test, load was applied until it reached a predetermined value; the deflection was read; load was removed; and readings of set at zero load taken. This was repeated several times and finally the load was increased continuously until failure of the specimen occurred. The several values to which the load was increased before testing to failure are indicated by the graph of test results (fig. 17). During the periods of load application, the upper end of the specimen was moved longitudinally at a rate of 0.2 in./min.

The walls were tested with the diagonal sheathing stressed in tension (fig. 5), which previous tests have indicated is the weaker direction.

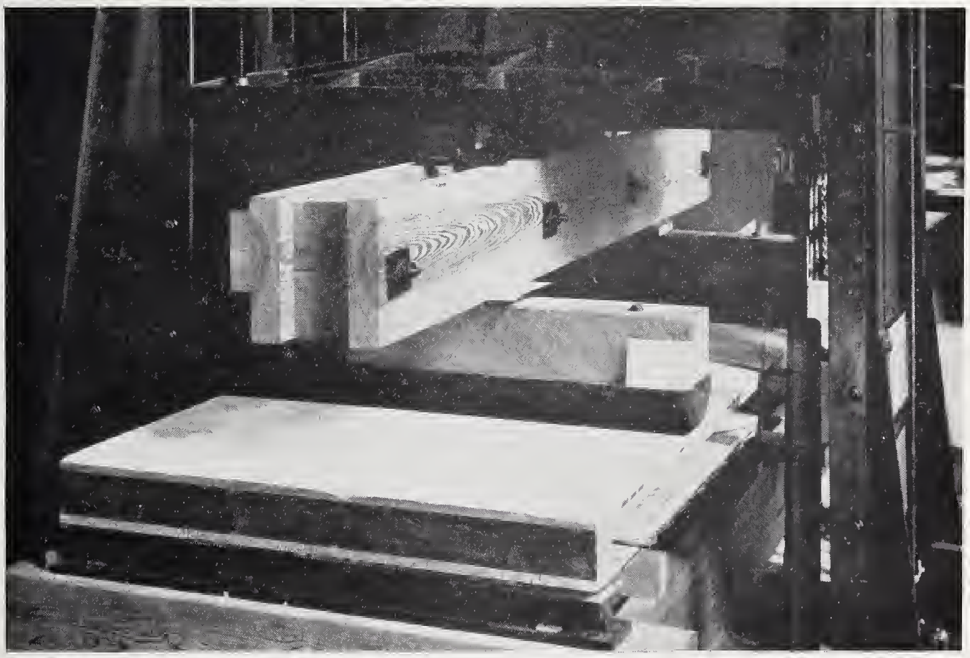

Figure 10.—*Wall specimen QA–T1 in position for transverse-load test.*

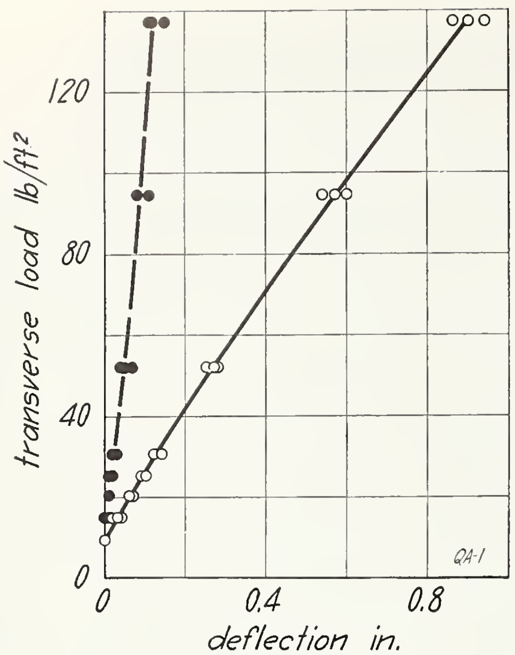

Figure 11.—*Transverse load on wall QA, load applied to inside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *QA-T1, T2,* and *T3* and on the span of 7 ft 6 in. Loads are in pounds per square foot of the area (span times the width of specimen 30 sq ft).

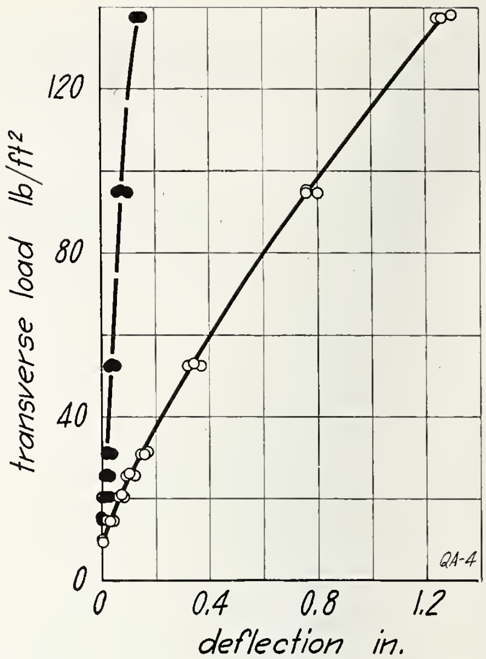

Figure 12.—*Transverse load on wall QA, load applied to outside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *QA-T4, T5,* and *T6* on the span of 7 ft 6 in. Loads are in pounds per square foot of the area (span times the width of specimen 30 sq ft).

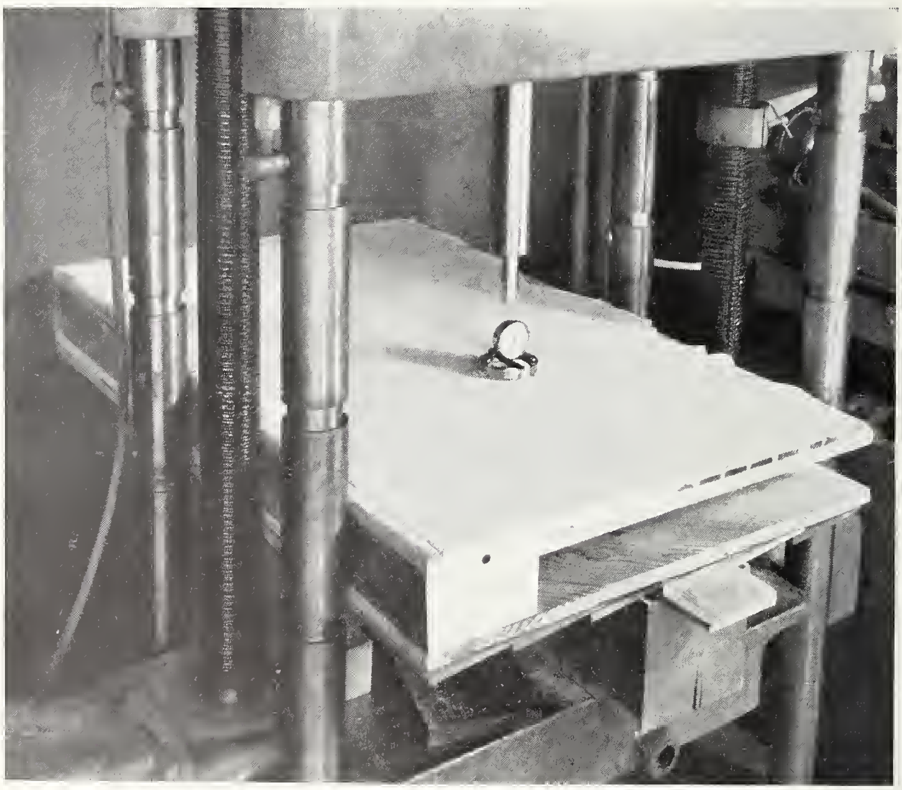

Figure 13.—*Wall specimen QA-P3 in position for the concentrated-load test.*

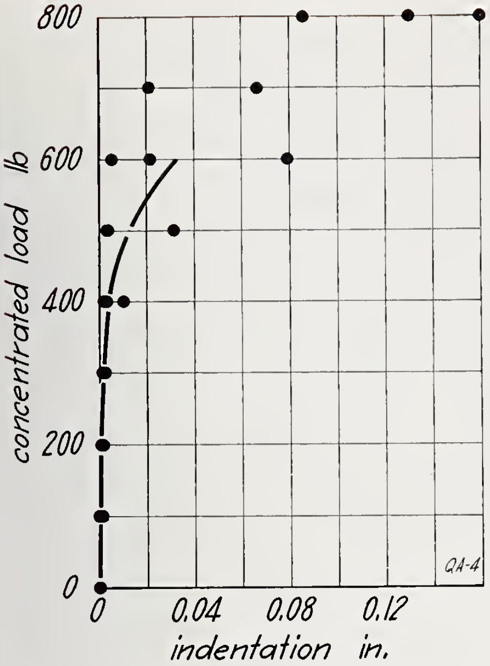

Figure 14.—*Concentrated load on wall QA, load applied to outside face.*

Load-indentation results for specimens *QA-P4, P5,* and *P6*.

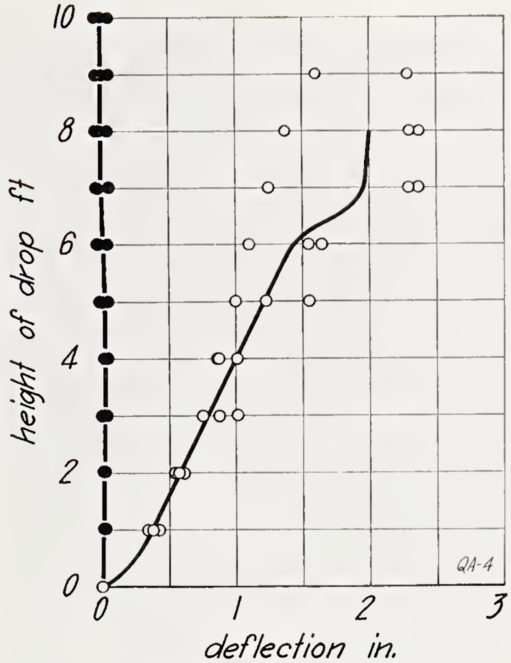

Figure 16.—*Impact load on wall QA, load applied to outside face.*

Height of drop-deflection (open circles) and height of drop set (solid circles) results for specimens *QA-I4, I5,* and *I6* on the span of 7 ft 6 in.

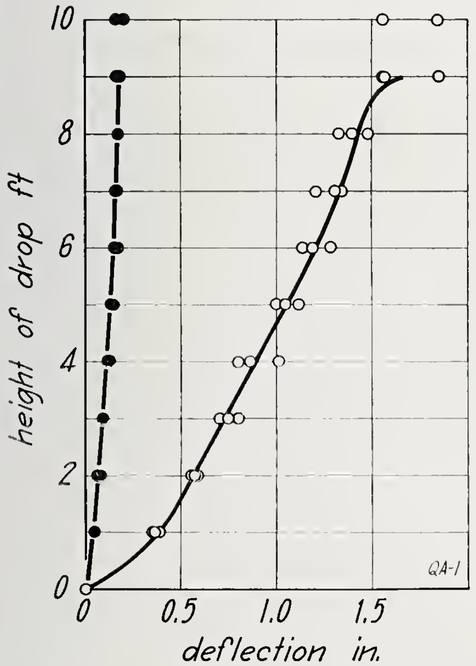

Figure 15.—*Impact load on wall QA, load applied to inside face.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *QA-I1, I2,* and *I3* on the span of 7 ft 6 in.

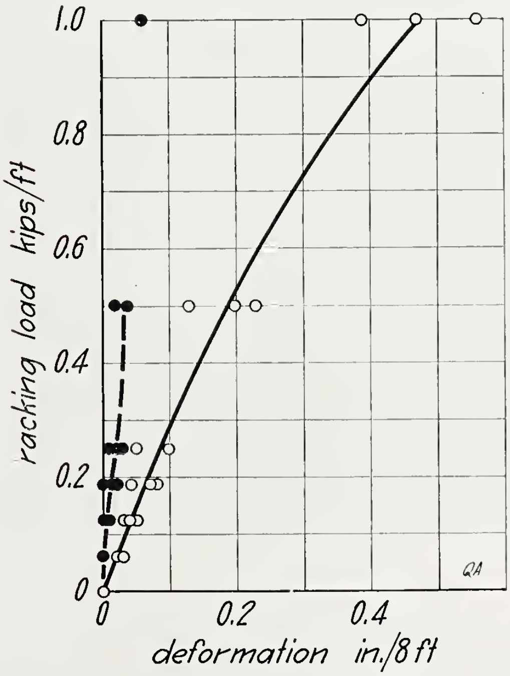

Figure 17.—*Racking load on wall QA.*

Load-deformation (open circles) and load-set (solid circles) results for specimens *QA-R1, R2,* and *R3*. Loads are in kips per foot of the face width of specimen (8 ft 0 in.).

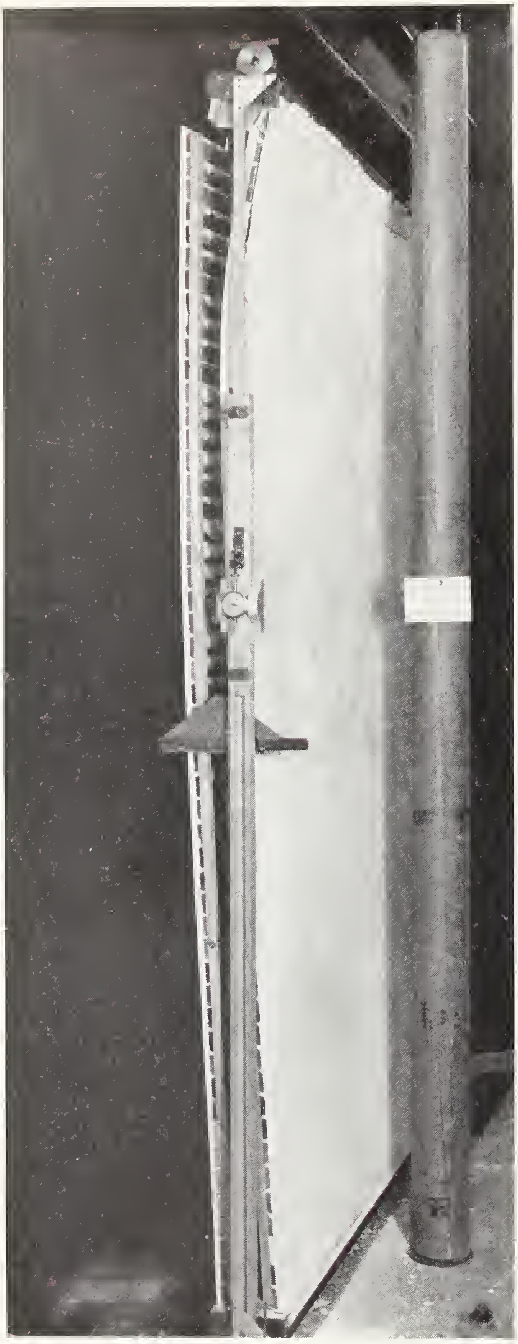

Figure 18.—*Partition specimen QD–C3 under compressive-load test.*

Shortening is read by means of the dial gage mounted on a telescoping rod attached to the bearing plates by pins centered at the middle of the thickness of the frame and in the planes of the ends of the specimen. Lateral deflection is the reading of the steel scale which is attached to the specimen at midheight against a fine wire stretched between end fittings of the telescoping rod and kept taut by rubber bands.

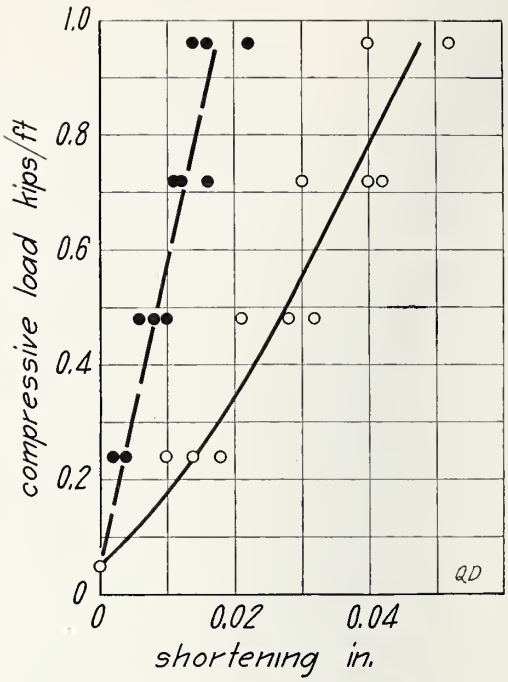

Figure 19.—*Compressive load on partition QD.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *QD–C1, C2,* and *C3.* Loads are in kips per foot of width of specimen (4 ft 0 in.).

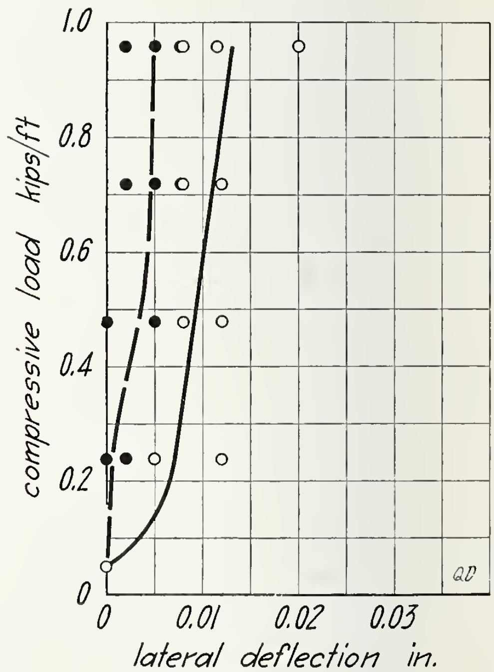

Figure 20.—*Compressive load on partition QD.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *QD–C1, C2,* and *C3.* Loads are in kips per foot of width of specimen (4 ft 0 in.).

TABLE 4.—*Structural properties of partition QD*

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the framing at time of test was 11.3 percent and the specific gravity (based on weight and volume when oven dry) was 0.51]

Load	Load applied	Specimen designation	Maximum height of drop	Indentation at 100 lb	Maximum load	Remarks
			ft	*in.*	*Kips/ft* [a]	
Compressive	Eccentric to top plate.[b]	*C1*			6.58	First plaster failure by crushing near bottom plate. Rocking over of upper plate due to eccentric loading caused plate to crush on compression side and pull away from studs on tension side.
		C2			6.44	Plaster cracked near bottom at 2.00 kips/ft. Final failure similar to specimen *C1*.
		C3			7.67	First plaster crack at 0.96 kip/ft, fourth loading. Final failure similar to specimen *C1*.
	Average				6.90	
					lb/ft²	
Transverse	One face	*T1*			240	First plaster crack in lower face at 52 lb/ft² at fifth loading. Failure due to cross grain tension in one outside stud followed by horizontal shear in center stud.
		T2			292	First plaster crack in lower face at 49 lb/ft² at fifth loading. Failure by tension in studs.
		T3			290	First plaster crack in lower face at 48 lb/ft ² at fifth loading. Failure by tension in studs.
	Average				274	
					lb	
Concentrated	One face	*P1*		0.004	185	Average of two tests—220 and 150 lb for loads at joint and center of width of lath, respectively.
		P2		.003	290	Loaded at joint between two laths.
		P3		.007	180	Loaded at center of width of lath.
	Average			0.005	218	
Impact	One face	*I1*	8.5			First plaster crack on both faces at 3-ft drop. One outside stud broke at 2-in. knot at 8.5-ft drop.
		I2	8.0			First plaster crack in both faces at 2.5-ft drop. Brash tension in center stud and tension in one side stud at 8-ft drop.
		I3	8.5			First plaster crack in lower face at 2.5-ft drop and top face at 3.5-ft drop. Tension in center stud at 8.5-ft drop.
	Average		8.3			
					Kips/ft [a]	
Racking	End of top plate	*R1*			1.06	First plaster crack at 0.88 kip/ft at sixth loading. Final failure due to plaster shearing keys.
		R2			1.00	First plaster crack at 0.38 kip/ft at fifth loading. Final failure due to plaster shearing keys.
		R3			1.05	First plaster crack at 0.50 kip/ft at fifth loading. Final failure due to plaster shearing keys.
	Average				1.04	

[a] A kip is 1,000 lb.
[b] Specimens loaded on top plate through knife edge at one-third width of frame from inside face of frame and supported at bottom on similar knife edge at center of frame.

The results for wall specimens *QA–R1*, *R2*, and *R3* subjected to the racking test are given in table 3 and in figure 17.

Failure was characterized by the sheathing pulling the nails and shearing from the lower plate [1] and by the studs breaking in bending or splitting from the nails driven through the lower plate into their ends.

VII. PARTITION *QD*—LOAD-BEARING

1. COMMENTS

Since nonload-bearing partitions are usually built the same as load-bearing partitions, no nonload-bearing partitions were included.

[1] Sheathing was less securely nailed to the lower or floor plate than to the upper. (See sec. VI-1.)

2. DESCRIPTION

The partitions were of the same construction as the walls with the exception that both faces were lathed and plastered and the impact specimens *QD–I1*, *I2*, and *I3* had single 2- by 4-in. top plates. As with the wall specimens, the floor plate of each 8-ft partition specimen was nailed to a 6- by 6-in. timber before plaster was applied to the specimen.

3. COMPRESSIVE LOAD

A partition specimen (*QD–C3*) under compressive load is shown in figure 18. The operation of the testing machine was as described for wall frames under section V–3.

The results for specimens *QD–C1*, *C2*, and *C3* are shown in table 4 and in figures 19 and 20.

The average maximum load of 6.90 kips/ft is approximately 35 percent of the computed value obtained by inserting in the Euler column

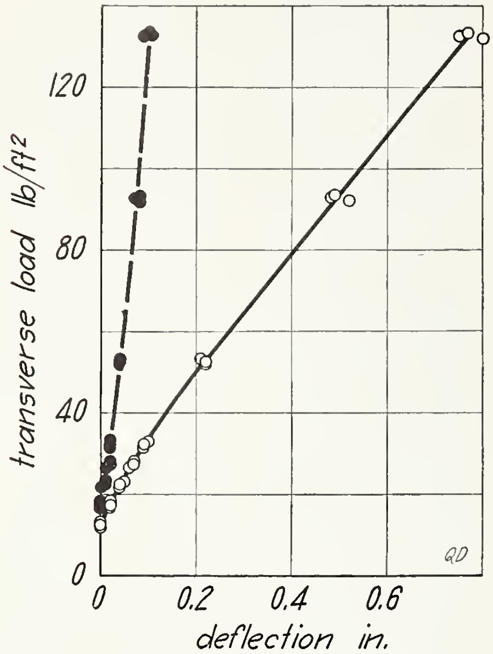

FIGURE 21.—*Transverse load on partition QD.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *QD–T1*, *T2*, and *T3* on the span of 7 ft 6 in. Loads are in pounds per square foot of the area (span times the width of specimen 30 sq ft).

formula the average value of stiffness derived from the transverse-load tests on specimens *QD–T1*, *T2*, and *T3*.

The three specimens failed by crushing of the plaster near the plates, crushing of the plates at the stud ends, tension plaster cracks after maximum load, and finally rocking over of the upper plate allowing the studs to kick out, as shown in figure 18, without breaking.

4. Transverse Load

The operation of the testing machine was as described for wall frames under section V–4.

The results of transverse-load tests (specimens *QD–T1*, *T2*, and *T3*) are given in table 4 and figure 21.

First failure in these panels was by tension in the plaster on the lower face. Final failure was by bending in the studs.

5. Concentrated Load

The results for specimens *QD–P1*, *P2*, and *P3* are given in table 4. Indentation on the plaster was so influenced by crushing and cracking of the plaster that consistent load-indentation readings were not obtained. Consequently only the indentation at 100 lb was recorded. Failure was by crushing and cracking of the plaster and breaking of the laths.

6. Impact Load

A setup for an impact test on a partition specimen is shown in figure 22.

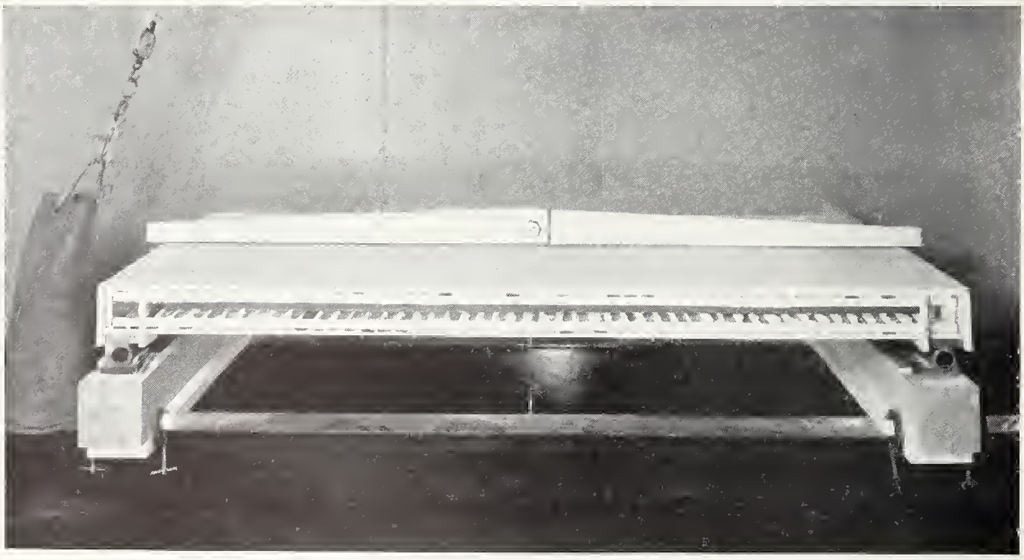

FIGURE 22.—*Partition specimen QD in position for impact-load test.*

The results for specimens *QD–I1*, *I2*, and *I3* are given in table 4 and figure 23.

The three specimens failed by breaking of the studs accompanied by shattering of the plaster and breaking of the laths.

7. Racking Load

A partition specimen (*QD–R1*) under the racking-load test is shown in figure 24. The

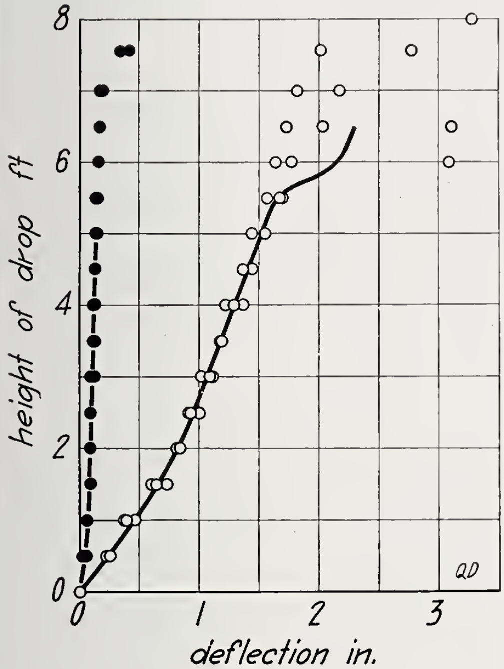

Figure 23.—*Impact load on partition QD.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *QD–I1*, *I2*, and *I3* on the span of 7 ft 6 in.

racking-load test was conducted as outlined for walls under section VI–6.

The results for specimens *QD–R1*, *R2*, and *R3* are given in table 4 and figure 25.

Final failure was due to shearing off of the plaster keys, thus lowering the resistance to distortion.

VIII. FLOOR *QB*

1. Description

Floor specimens (fig. 26) were 4 ft wide by 12½ ft long and consisted of three 2- by 8-in. joists (actual dimensions 1$\frac{9}{16}$ by 7⅝ in.) spaced 16 in. on centers and symmetrically placed with respect to the width. A 2- by 8-in. by 4-ft header was fastened to each end of the speci-

Figure 24.—*Partition specimen QD–R1 under racking-load test.*

men by two 16d common wire nails driven into the end of each joist. The subfloor, which was applied in full-length pieces, was laid diagonally at an angle of about 45° with the joists, and nailed to each joist and header with two 8d common nails. Building paper was laid between the subfloor and the finish floor, then one row of 1- by 4-in. cross bridging, each piece of which was nailed at each end with two 8d nails, was applied at midlength of the specimen. The finish floor was laid 1 week before test and nailed with 8d casing nails. The lower surface

was lathed, the joints being broken for each course of eight laths, and plastered.

2. Transverse Load

The operation of the testing machine was as described for wall frames under section V–4,

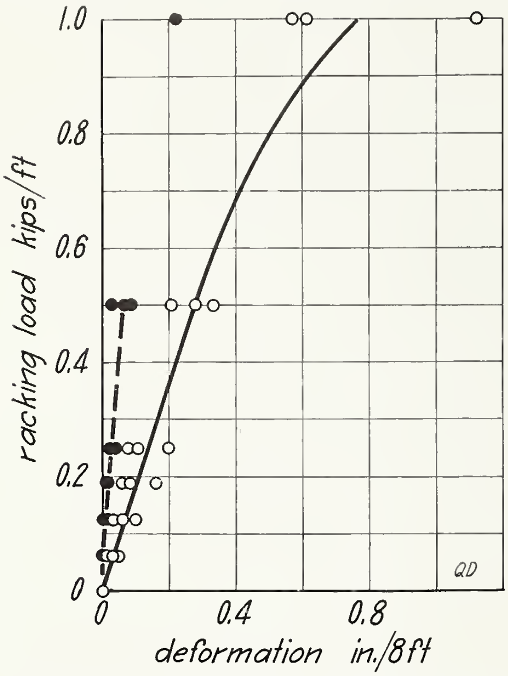

Figure 25.—*Racking load on partition QD.*

Load-deformation (open circles) and load-set (solid circles) results for specimens *QD–R1*, *R2*, and *R3*. Loads are in kips per foot of the face width of specimen (8 ft 0 in).

except that the rate of movement of the head was about 0.08 in./min, which was increased to 0.13 in./min in the final run to failure.

The results for specimens *QB–T1*, *T2*, and *T3* are given in table 5 and figure 27.

First failure was by cracking of the plaster at relatively low loads. Final failure was by tension in the joists, influenced in specimens *T1* and *T3* by knots.

3. Concentrated Load

The results for specimens *QB–P1*, *P2*, and *P3* are given in table 5 and figure 28.

Failure was by local splitting and breaking of the flooring and subflooring as the tool penetrated the floor panel.

4. Impact Load

The results for specimens *QB–I1*, *I2*, and *I3* are given in table 5 and figure 29.

The floor panels showed no failure in the joists at the final drop from a height of 10 ft. The plaster broke loose very generally in the central portion of specimens *I1* and *I2*, and only slightly at one edge of *I3*.

IX. ROOF *QC*

1. Description

Roof specimens (fig. 30) were 4 ft wide by 14 ft 6 in. long. They consisted of two 2- by 6-in. (actual 1⅝ by 5⅝ in.) rafters spaced 24 in. on centers and symmetrically placed with respect to the width. A 2- by 6-in. header 4 ft long was fastened to each end of the specimen by two 16d common wire nails driven into the end of each joist. The roof boards were laid snug, perpendicular to the rafters, and nailed with two 8d nails at each rafter crossing and were covered with building paper and shingles laid with a 5-in. exposure.

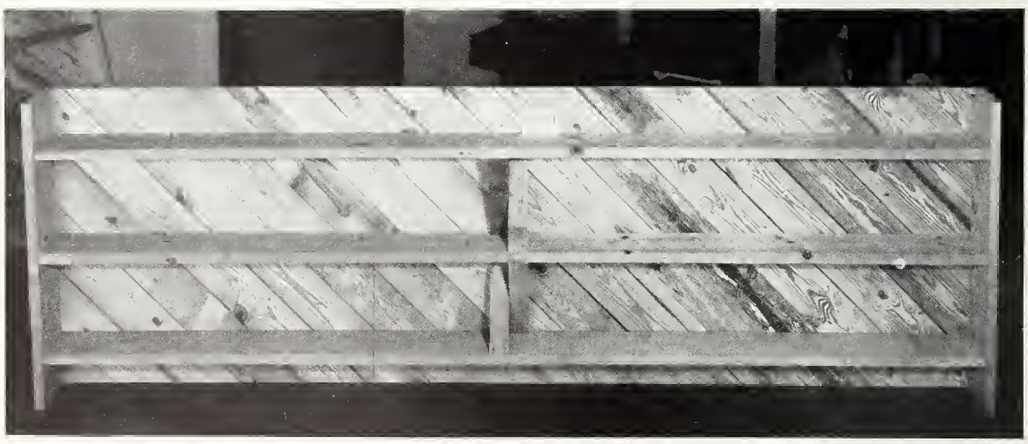

Figure 26.—*Under side of floor specimen QB before plastering, showing construction.*

Table 5.—*Structural properties of floor QB*

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the framing at test was 10.5 percent and the specific gravity (based on weight and volume when oven dry) was 0.50]

Load	Load applied	Specimen designation	Maximum height of drop[a]	Indentation at 100 lb	Maximum load	Remarks
			ft	*in.*	*lb/ft²*	
Transverse	Upper face	*T1*			242	First plaster crack at 29 lb/ft² at third loading. Failure by tension at knots in 2 joists.
		T2			259	First plaster crack at 31 lb/ft² at fourth loading. Failure by tension in joists.
		T3			358	First plaster crack at 39 lb/ft² at fourth loading. Failure by tension in joists influenced by knots.
	Average				287	
					lb	
Concentrated	Upper face	*P1*		0.000	3,500	Loaded at center of flooring strip over joint in subfloor.
		P2		.000	3,320	Loaded at center of flooring strip over center of subfloor board.
		P3		.000	3,610	Do.
	Average			0.000	3,477	
Impact	Upper face	*I1*	[a] 10.0			First plaster crack at 4.5-ft drop. No failure in flooring or joists.
		I2	[a] 10.0			First plaster crack at 4-ft drop. No failure in flooring or joists.
		I3	[a] 10.0			First plaster crack at 6.5-ft drop. No failure in flooring or joists.
	Average		[a] 10.0			

[a] Test discontinued at 10-ft drop.

2. Transverse Load

The operation of the testing machine was as described for wall frames under section V-4, except that the rate of movement of the head was 0.13 in./min and was doubled in the final run to failure.

The results for specimens *QC–T1, T2,* and *T3* are given in table 6 and figure 31.

Table 6.—*Structural properties of roof QC*

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the rafters at test was 8.5 percent and the average specific gravity (based on weight and volume when oven dry) was 0.44]

Load	Load applied	Specimen designation	Indentation at 100 lb	Maximum load	Remarks
			in.	*lb/ft²*	
Transverse	Upper face.	*T1*		84.7	Tension in both rafters.
		T2		113.2	Tension in one rafter.
		T3		74.0	Tension in both rafters.
	Average			90.6	
				lb	
Concentrated.	Upper face.	*P1*	0.000	1,670	Load on one roof board only.
		P2	.001	1,760	Load at least 1 in. from joint in roof.
		P3	.001	1,350	Loaded over joint between two roof boards.
	Average		0.001	1,593	

Failure was by tension in the rafters.

3. Concentrated Load

The results for specimens *QC–P1, P2,* and *P3* are given in table 6 and figure 32.

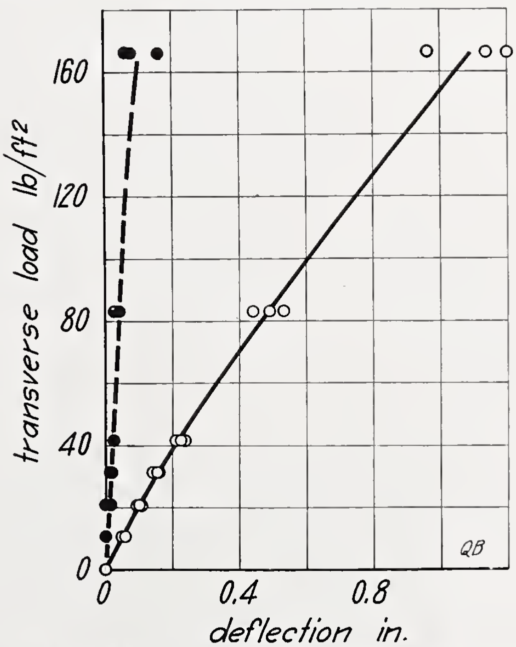

Figure 27.—*Transverse load on floor QB.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *QB–T1, T2,* and *T3* on the span of 12 ft 0 in. Loads are in pounds per square foot of the area (span times the width of specimen 48 sq ft).

Failure was by the test tool puncturing the shingles and breaking through the roof board.

X. LOADS AND DEFLECTIONS IN TRANSVERSE TESTS

Results of transverse tests on walls, partitions, floors, and roofs are expressed in this report in terms of load per square foot of area although in test the load was applied at the quarter points of the span and thus was not uniformly distributed. The deflections recorded were measured at midspan.

Maximum loads as found in the transverse tests are practically the same as would be found from tests with the load uniformly distributed. The deflections in the earlier stages of the tests are 10 percent greater than would be caused by uniformly distributed load of the same magnitude.

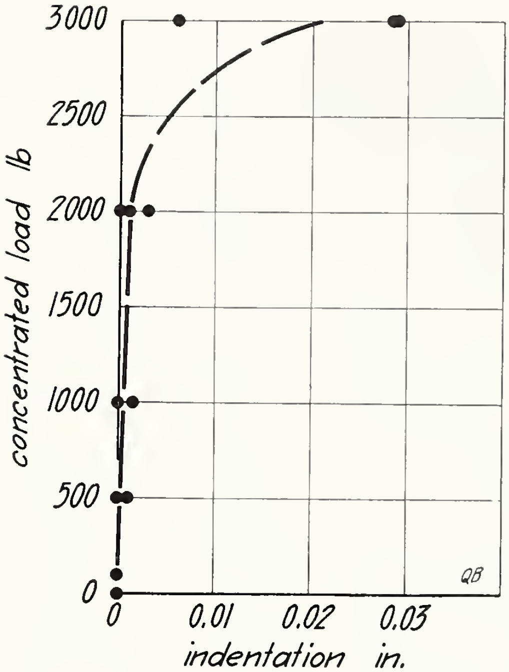

FIGURE 28.—*Concentrated load on floor QB.*

Load-indentation results for the specimens *QB-P1*, *P2*, and *P3*.

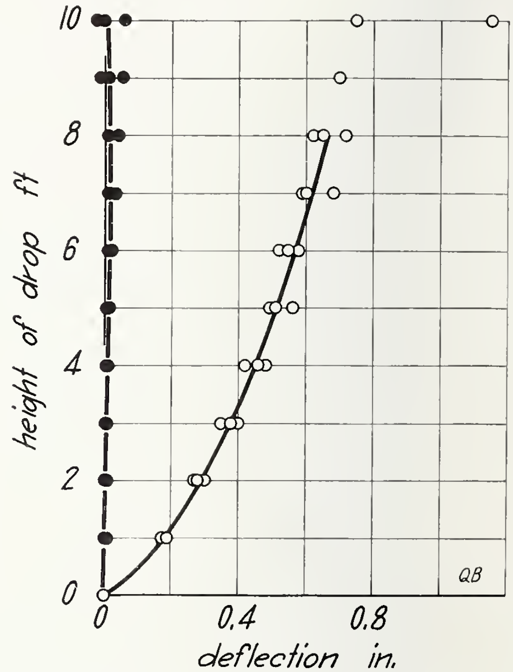

FIGURE 29.—*Impact load on floor QB.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *QB-I1*, *I2*, and *I3* on the span of 12 ft 0 in.

XI. SIGNIFICANCE OF SET READINGS

Readings of set in the compressive-, transverse-, impact-, and racking-load tests on all covered specimens were so influenced by friction between the parts, closing of parts, and in some instances crushing of the plaster or plates that

FIGURE 30.—*Under side of roof specimen QC, showing construction.*

they are of doubtful significance. For example, in the transverse-load test the set reading would in many instances entirely disappear with a slight pressure momentarily applied underneath the panel. Under the impact test, vibrations were set up, and when the panel came to rest it might be at either a low or a high point in its amplitude, due to friction between the various parts. The panel coming to rest at the high point would account for the negative

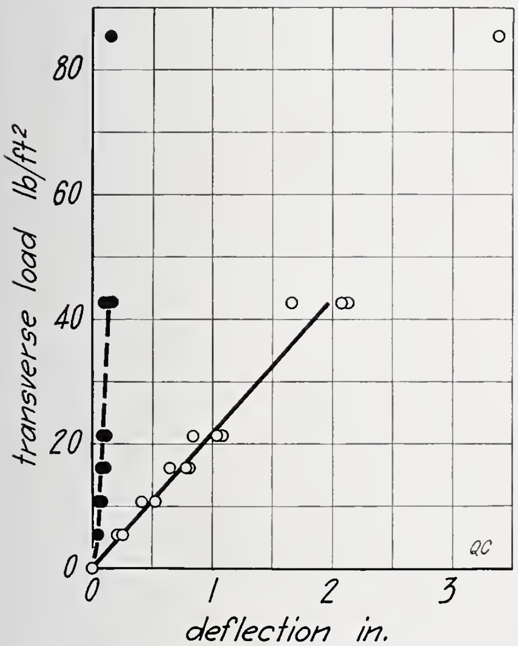

FIGURE 31.—*Transverse load on roof QC.*

Load-deflection (open circles) and load-set (solid circles results for specimens *QC-T1*, *T2*, and *T3* on the span of 14 ft 0 in. Loads are in pounds per square foot of the area (span times the width of specimen 56 sq ft).

set obtained at a 10-ft height of drop in the walls tested with the outside face up (fig. 16).

XII. WEIGHTS

The weights of the various constructions before plastering and at time of test have been summarized in table 7. The weights of plaster were found by differencing the weights before plastering and at time of test, which was 28 days later. Change of weight of parts other than plaster over this period was no doubt very small and has been disregarded in deriving the figures for weight of plaster.

TABLE 7.—*Weights of constructions and plaster*

Construction	Weight without plaster	Weight with plaster	Weight of plaster (age 28 days)
	lb/ft²	*lb/ft²*	*lb/ft²*
Wall	5.1	10.0	4.9
Partition	3.0	12.8	4.9
Floor	----	13.2	---
Roof	4.6	----	---

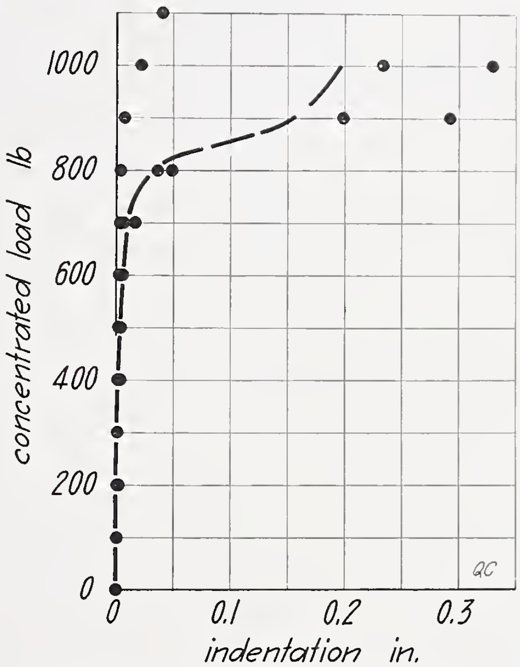

FIGURE 32.—*Concentrated load on roof QC.*

Load-indentation results for specimens *QC-P1*, *P2*, and *P3*.

XIII. TWO METHODS OF TESTING WALLS UNDER COMPRESSIVE LOAD

1. COMMENTS

In BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, p. 7, the compressive load is described as being applied to the specimen as a column having a flat end at the bottom. For the reasons given in section III–3, Test Procedure, the walls and partitions tested for this report were supported by a knife-edge at the bottom. To determine the effect of the type of lower bearing on the results for compressive loading, specimens *ZZ* were tested in the laboratory of the National Bureau of Standards at Washington, D. C., using knife-edge and flat-end bearings at the bottom. They were built

under the supervision of a member of the staff of the Forest Products Laboratory who assisted in the tests.

2. Description

Three specimens were made for each of the two types of lower bearing. The framing for these specimens consisted of 2- by 4-in. (nominal) studs, a doubled 2- by 4-in. plate at the top, and a single 2- by 4-in. floor plate at the bottom. These parts were arranged in like manner to the 4-ft wall specimens (*QA*) described under section VI–1.

Douglas fir was used for the framing; and, in order to avoid any effect of defects on the desired comparison, straight-grained material free from knots was selected. To further assure valid comparison between tests with the two kinds of end bearing the specimens were paired in such a manner that studs cut from end-to-end positions in a 2- by 10-in. plank, jointed straight, and surfaced to width, occupied like positions in the specimens of a pair and were oriented alike, i. e., with the same end up and the same edge toward the inside face of the specimen. Floor plates and top-plate parts were similarly matched. The frames were faced on both sides with 25/32-in. fiberboard in two pieces, with the junction on the center stud. Each piece of fiberboard was nailed to the top and floor plates and to the center stud with 8d common nails spaced 3 in. Nail spacing along the other studs was 6 in., 8d common nails being used on the outside face of the specimen and 6d casing or finish nails on the inside face.

3. Test Results

The data from the tests in series *ZZ* are given in table 8.

Table 8.—*Results of compressive-load tests on wall specimens ZZ comparing knife-edge to flat-end bearing*

Specimen designation	Bottom bearing	Maximum load	Lateral deflection midheight at—			Shortening at—	
			12,000 lb	20,000 lb	28,000 lb	12,000 lb	20,000 lb
		lb	*in.*	*in.*	*in.*	*in.*	*in.*
C1a	Flat	28,000	0.12	0.21	0.40	0.05	0.10
C1b	Knife edge	29,000	.08	.16	.32	.06	.11
C2a	Flat	32,000	.02	.10	.36	.08	.13
C2b	Knife edge	34,000	.05	.12	.38	.08	.12
C3a	Flat	25,740	.03	.08		.05	.11
C3b	Knife edge	24,500	.05	.18		.06	.15
Average	Flat	28,580	0.05	0.13	0.38	0.06	0.11
Average	Knife edge	29,170	0.06	0.15	0.35	0.07	0.13

In the tests of series *ZZ*, as well as in other compressive-load tests of wood constructions with 2- by 4-in. studs and doubled 2- by 4-in. top plates, final failure was preceded by severe eccentric crushing of the plate against the ends of the studs. (The eccentricity was so great in some instances that studs and plate were in contact over only part of the width, as shown in fig. 1.)

In the special tests with flat bearing at the lower end of the specimen, eccentric yielding also occurred at the bearing of studs on th floor plate and contributed to the eccentricity of loading, although it was not great enough to be apparent as visible crushing.

In many of the tests on specimens with doubled 2- by 4-in. top plates the eccentric crushing of the under side of the plate against the ends of the studs caused the plates to roll and carry the upper ends of the studs so far laterally that "jack-knifing" or collapse of the specimen and apparatus occurred, probably without the full load capacity of the studs being developed. This was true in the tests of wall frames *QAf* (see fig. 1 and table 2) in partition specimens *QD* (see table 4) and in all but one, *C1b*, of the wall specimens *ZZ*. For all the other specimens, lateral movement at the top of the studs greatly increased the effective eccentricity of loading.

4. Discussion

The tests on the *ZZ* specimens were carried out subsequent to those described in preceding parts of this report but in advance of any other tests of wood constructions under this program. On the basis of the results of tests on *QA*, *QD*, and *ZZ* specimens and in order to obtain uniformity with tests on other types, it was decided that in all future compressive-load tests of wood constructions under this program flat bearing would be used at the lower end in accordance with BMS2.

Considering the numerical results listed in table 8 and the behavior observed in tests of the *ZZ* series and other wood constructions, it is improbable that the values from the present tests on walls (*QA*), partitions (*QD*), and wall frames differ significantly from those that would have resulted had flat bearings been used.

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